A STUDY OF MILLISECOND PULSES CONTAINED IN THE DECAMETRIC RADIO RADIATION FROM JUPITER

by
RICHARD THOMAS LEE

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Richard Thomas Lee, M.S.
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Various workers have reported the observation of very short pulses in the decametric radiation from Jupiter. It is possible that pulses of terrestrial origin could have been confused with Jovian radiation. Thus it is the purpose of this research to observe, to identify conclusively and to study the nature of these pulses.

Observations have been made of the left- and right-handed components of the pulses, which have arbitrarily been called I-pulses, at 16, 18 and 22 Mc/s and of the total power at 14 and 26 Mc/s. A minimum time resolution of 7 msec was obtained with an eight-channel, electric writing, high speed recorder system. In addition to the criteria usually accepted for identification of Jovian radiation, polarization and bandwidth have been used to discriminate the I-pulses from static pulses. An 18 Mc/s phase-switched interferometer and an 18 Mc/s null antenna were used as an additional means of verifying that Jupiter was active while I-pulses were received.

author

The I-pulses have been observed to have durations as short as or shorter than 10 msec with different forms of grouping during an event. The I-pulses were found to be correlated with System III longitude on Jupiter, being more closely associated with "sources" B and C than to "source" A. The null region D was also shown. The I-pulses were narrow banded and polarized in much the same way as normal Jovian radiation. Selected events showed similar axial ratio distributions.

ACKNOWLEDGEMENTS

I wish to thank Dr. Edward E. Baart and Professor Colin H. Barrow for much of the work essential for this research; for organizing the electronics, for many hours of observations and for helpful discussions and suggestions. Dr. Baart established the time constant and chart speed system used with the high speed recorder and devoted considerable time to a preliminary study of the records. I also wish to extend my thanks to Miss Barbara Dow, Miss Judy Herr and Miss Janet Van Pelt for their help with data reduction and to Mr. James Merritt for assistance with computer programming and proof reading. This research was supported by the National Aeronautics and Space Administration (Grant Number NSG-224-61).

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INTRODUCTION

In 1955 while observing the Crab Nebula at 22 Mc/s with a Mills Cross antenna, Burke and Franklin[1] detected a discrete source of radio noise which moved slowly in right ascension during the course of several months. They found that at all times when the radio noise was observed, the position of the planet Jupiter coincided with the position of the radio source. Thus it was discovered that Jupiter is an emitter of strong decametric radio radiation.

Further observations have shown that the radiation occurs intermittently in events or radio storms that may last from a few minutes to several hours. These events consist of "bursts" of radiation which, by definition[2], have separations of one second or longer. Following Recommendations for Standardization of Reporting Procedures[2], the letters L, N, and S are assigned to the bursts according to their duration. These classifications, to which we have arbitrarily added the classification "I-pulse" for bursts shorter than 50 milliseconds, are summarized in Table 1. For purposes of discussion, all Jovian radiation except I-pulses will be called normal pulses or normal radiation.

TABLE 1

NASA CLASSIFICATION OF BURSTS ACCORDING TO THEIR DURATION

Character of Emission		Suggested NASA Classification	Name
Burst Type	Time Scale in seconds		
Very short	Less than 0.05	1	I
Short	0.05 - 0.2	1	S
Normal	0.2 - 2.0	2	N
Long	Greater than 2.0	3	L

Observations have been made at frequencies from 4.8 Mc/s [3] to 38 Mc/s [4] with the probability of occurrence being greatest for frequencies below 20 Mc/s. The radiation has been found to be narrow banded with bandwidths from about 0.1 Mc/s to 2.0 Mc/s. The polarization of the radiation has been studied quite extensively and has been found to be mostly elliptically polarized with a predominant part in the right-handed sense.

An early statistical study by Shain[5], using old galactic records, showed that there is a correlation between the radiation received and the rotation period of the planet. To demonstrate this correlation, Shain plotted periods of occurrence of radiation against the longitude of the central meridian on Jupiter at the time of observation. The correlation was made both for System I and System II longitudes which are defined for the equatorial region and remainder of the planet respectively*. It is fairly obvious from Figure 1 that there appears to be a region or 'source' on the planet with which the radiation is associated. This source seems to drift in time, negatively for System II and positively for System I. A new longitude system, System III or λ_{III}, based on radio observations has been defined[6,7] (epoch 1957.0) with a period of $9^h\ 55^m\ 29^s.37$.

When the number of events is summed for each 5° interval of longitude it appears that there may be three or four sources of radiation on the planet. It is noticeable that the sources are not 180° wide as would be expected for an isotropic radiator located on the planet. Thus the radiation may have its origin below some refracting medium such as the magnetosphere and may be refracted or beamed into cones by it.

In 1964, Bigg[8] found that the Jovian moon Io has some effect on the radiation from Jupiter. He plotted the departure, in degrees, of Io from superior geocentric conjunction** against an arbitrarily defined activity index.

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*The visible disc of Jupiter consists of cloud belts with varying rotation periods. The average rotation periods of the regions mentioned are $9^h\ 50^m\ 30^s.003$ and $9^h\ 55^m\ 40^s.632$ respectively.

**Superior geocentric conjunction occurs when Io crosses the Earth-Jupiter line on the far side of Jupiter.

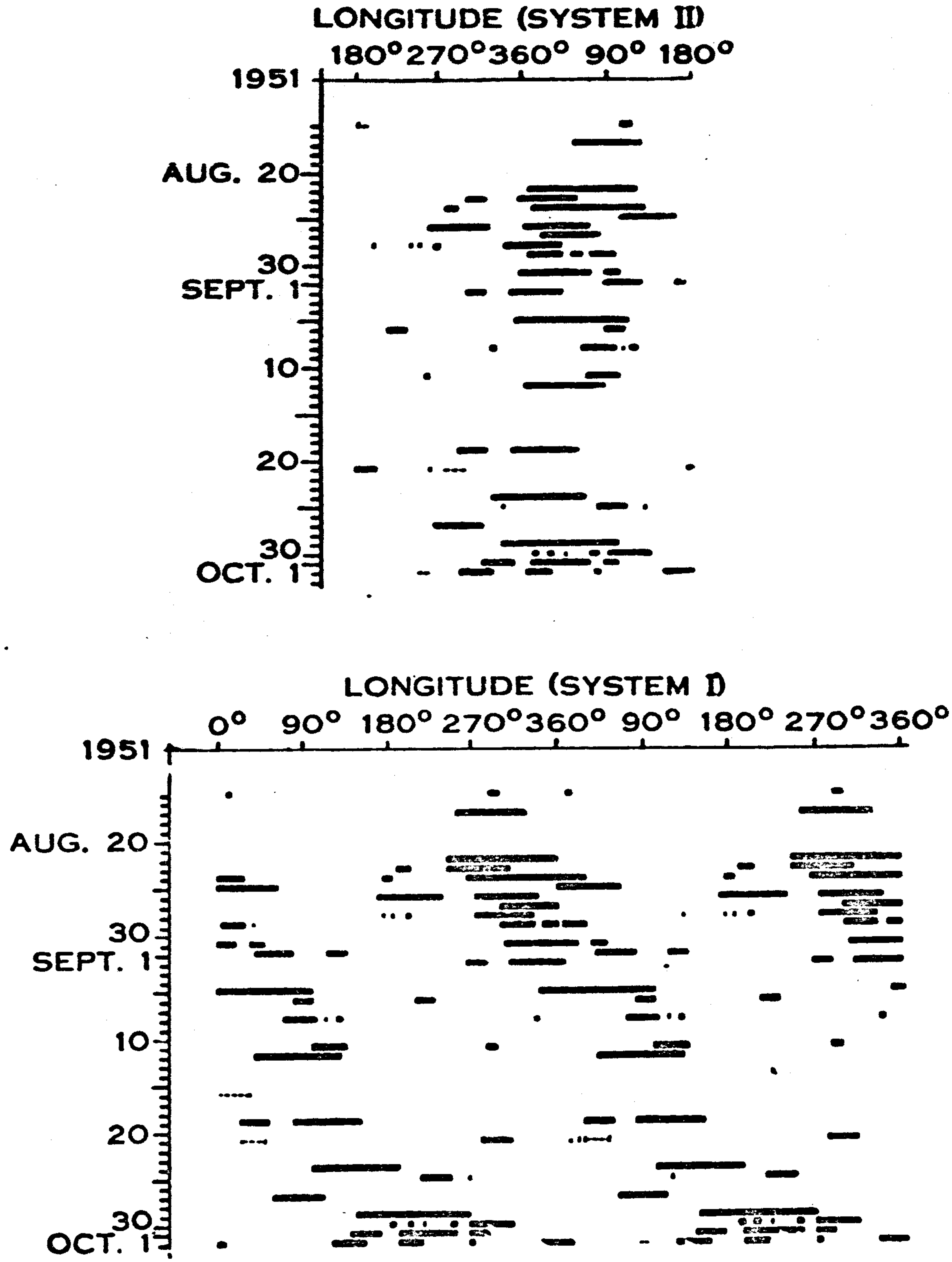

Fig. 1--Central meridian longitudes on Jupiter when radio bursts were being received (Shain[5]).

It was found that when Io is 70° to 110° and 220° to 270° away from conjunction the radiation is greatly enhanced. This same correlation study has been made for other of Jupiter's moons but the results have not been very conclusive.[9]

In 1956, Kraus[10] reported the observation of very short pulses that appeared to be in the radiation from Jupiter. These pulses had a duration of about 10^{-3} to 10^{-2} seconds and there seemed to be some regularity in the way in which the pulses were received. They appeared to arrive in pairs or triplets with separations up to one second. He postulated that the pulses had their origin below a Jovian ionosphere and that a pulse would be seen two or more times due to the fact that it would be reflected at the Jovian ionosphere and at the solid surface of Jupiter.

Gallet[11] also reported observing pulses with a very short duration. These he arbitrarily called S-pulses as distinct from pulses of duration two seconds or longer which were referred to as L-pulses*. Gallet's S-pulses might be received on one frequency and L-pulses on another or one frequency might be inactive while the other was active. The pulses showed a considerable tendency toward grouping and in between groups practically no pulses were present. A group of L-pulses may last for some minutes while a group of S-pulses may last from ten to twenty seconds.

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*This is not the NASA classification

Observations of millisecond pulses have also been made by Riihimaa[12] at the University of Helsinki. In 1964 Riihimaa reported the observation of three "pip storms" on the days September 22, 29, and October 30. In these events the pulses had high intensities, appeared first in thin groups which increased in density, and finally decreased again, their occurrence varying from a few to a few hundred per minute. Very often the pulses exhibited bandwidths narrower than that of the spectrograph in use, and were gathered into bands that drifted across the operating range, always negatively, at rates varying from 100 to 125 Kc/s per minute. The interferometer he was using had deflections of proper phase when a group with sufficient density crossed its operating frequency. The pulses were observed in the absence of interference, with Jupiter in the reception beam of the antenna and with no sign of possible malfunction of equipment. Observations of short pulses have also been reported by Olson and Smith[13], at the University of Florida.

In September, 1965, Dr. E. E. Baart, on leave from Rhodes University, South Africa, came to Florida State University to conduct an experiment to study these very short pulses. At this time considerable doubt existed as to whether or not the pulses were of Jovian origin. Often during observation, pulses of terrestrial origin, similar to the millisecond pulses described here, are detected by the receivers. It is possible that these terrestrial pulses, known as atmospherics or static, could have been confused with Jupiter radiation. Very few observations had been made at this time with sufficient time resolution to measure the duration of the pulses, and the polarization of the I-pulses had not been studied unambiguously.

It is the purpose of this research to observe, to identify conclusively, and to study the nature of these pulses and their relation to the longer time structure of Jovian radiation.

EQUIPMENT

Antennas

Observations of I-pulses were made at 14, 16, 18, 22 and 26 Mc/s. The antennas were of two types: broadside arrays and crossed five-element Yagis. A broadside array consists of a number of half-wave dipoles; the directive characteristics as well as the overall gain depends upon the number and configuration of the dipoles, their separations, height above the ground and feeding arrangements. Figures 2 and 3 give the configuration, separation and number of dipoles and their beam pattern. Table 2 gives the type of observation made, the height above the ground, the gains and the periods of observation for each antenna. Information on the design, construction and feeding arrangements of arrays may be found in a publication by the American Radio Relay League[14].

The Yagi antenna is commercially produced and is shown with its beam pattern in Figure 4. The first three elements on the Yagi are directors, the next is the receiving element and the last is a reflecting element. The receiving element is an electrical 1/2 wavelength long and is separated from the reflecting element and the third directing element by about 1/4 wavelength. Information on the Yagi is also contained in Table 2.

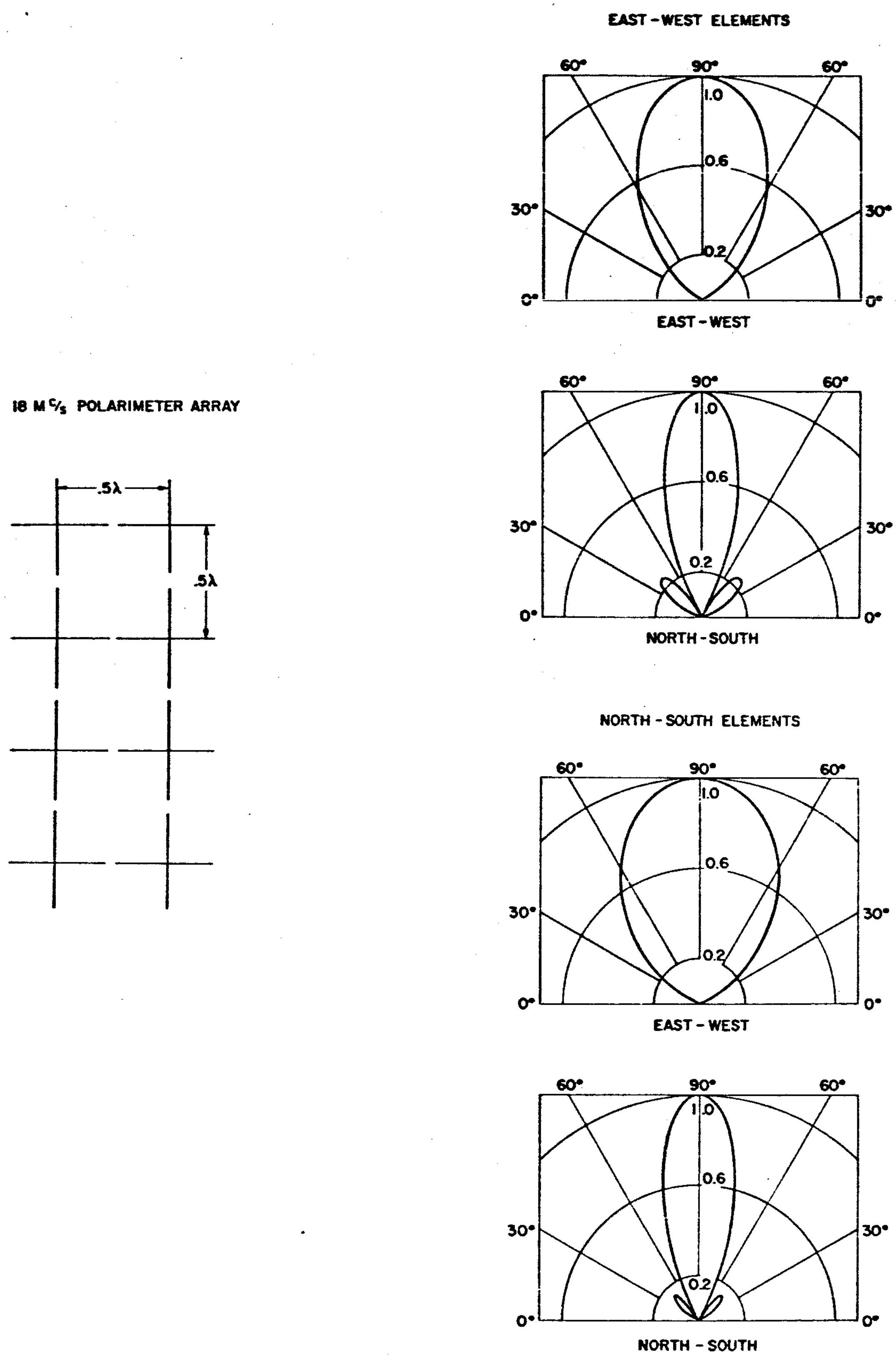


Fig. 2--18 Mc/s polarimeter array with its beam patterns.

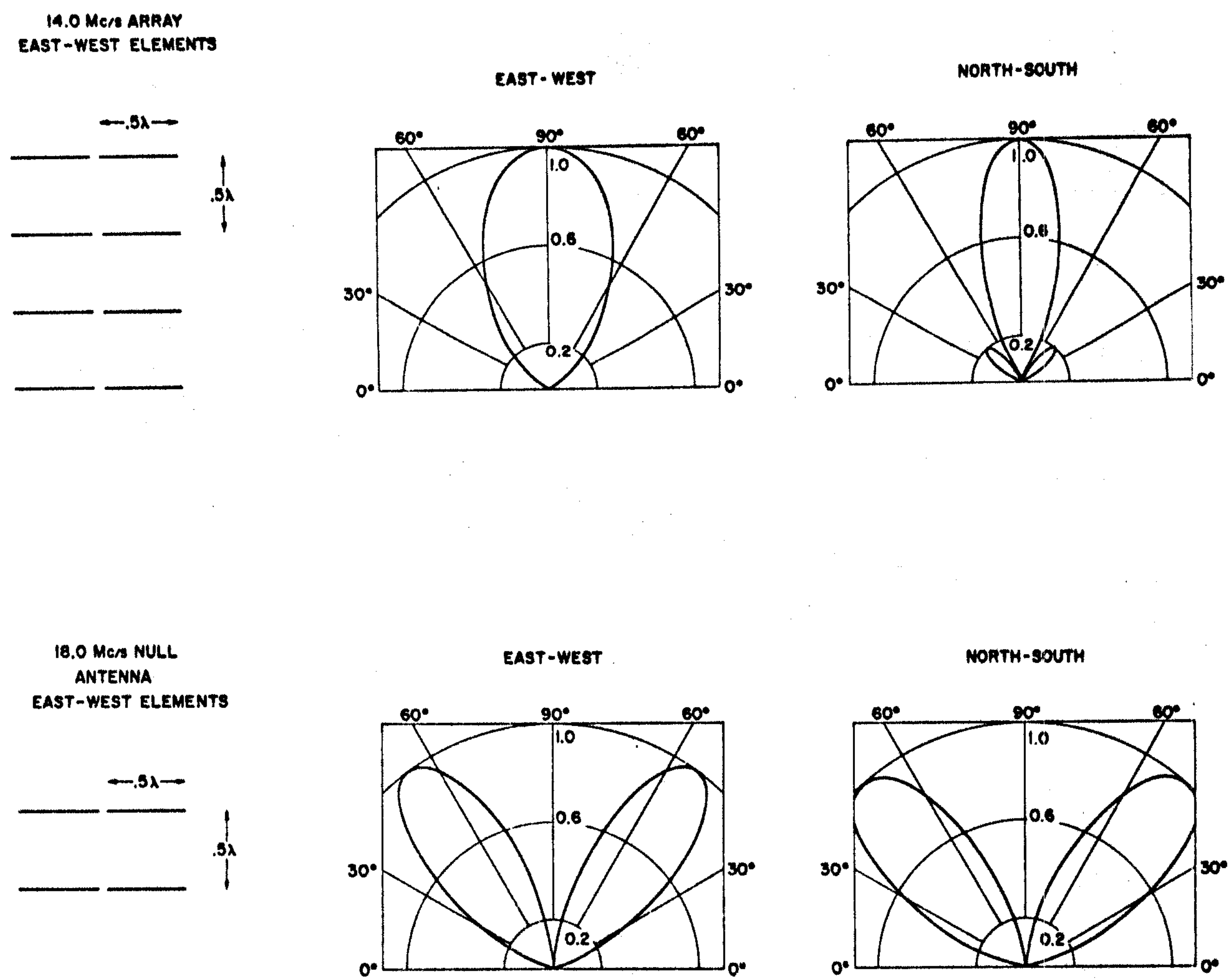


Fig. 3--14.0 Mc/s array and 18.0 Mc/s null antenna and their beam patterns.

TABLE 2

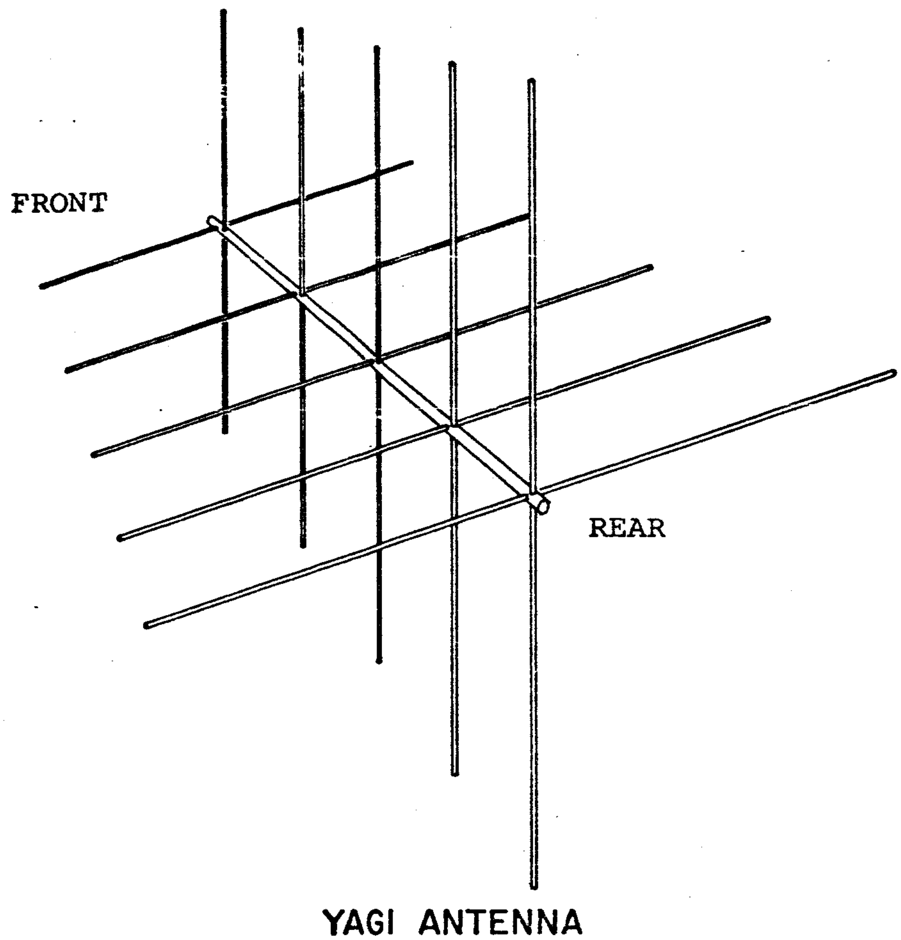
ANTENNA CHARACTERISTICS WITH DATES OF OBSERVATION

Frequency Mc/s	Type[a]	Antenna	Height above[b] Ground wavelengths	Estimated[c] Gain db	Period	
					From	To
14	T.P.	8 element array	1/8	10.8	December 28	March 26
16	L.H. R.H.	Yagi	---	10.5	November 21	March 26
18	L.H. R.H.	Yagi	---	10.5	December 6	March 25
	P.S.I.	Two 8 element arrays	1/4	14.0 each	December 31 January 27	January 11 March 26
22	L.H. R.H.	Yagi	---	10.5	November 21	February 4
26	T.P.	Yagi	---	10.5	November 21	December 1

[a] T.P., L.H., R.H., P.S.I. and N.A. are the abbreviations for total power, left-handed polarization, right-handed polarization, phase-switched interferometer and null antenna respectively.

[b] The base of the 16, 22 and 26 Mc/s Yagis were fixed to the ground and the 18 Mc/s Yagi was alt-asimuthally mounted on a 35 ft. tower.

[c] The value for the Yagi is given by the manufacturer as 12.5 db. This is regarded as optimistic by about 2 db.



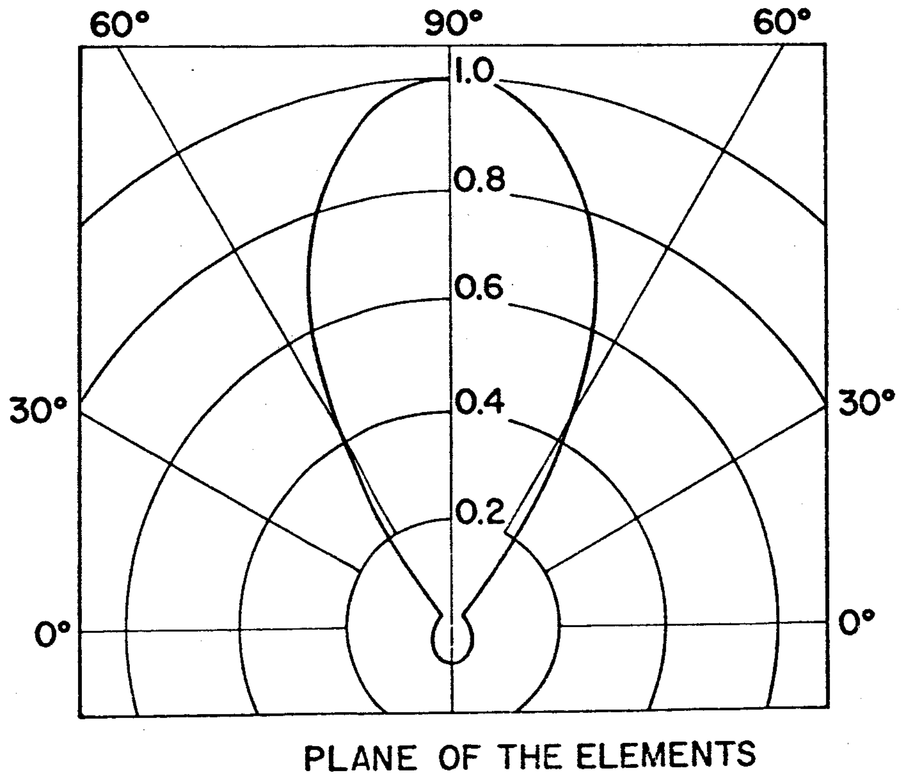


Fig. 4--Yagi type antenna and its beam pattern.

The 18 Mc/s phase-switched interferometer, which is not included in Figure 2 or 3, consists of two broadside arrays with a separation of 16 wavelengths. The configuration of each array and separations between the dipoles is the same as that of the east-west elements of the 18 Mc/s polarimeter shown in Figure 3. The beam pattern of the antenna is not feasible to represent since it contains 27 narrow lobes which are 3°.5 wide near the vertical and which widen slowly toward the horizon. The envelope of the lobes has the shape of the east-west beam pattern of the east-west elements of the 18 Mc/s polarimeter array. The height above the ground, gain and the dates of observation with the antenna are shown in Table 2.

Receiving and recording

The polarization observations at 16, 18 and 22 Mc/s were made using the method of Barrow[15] in which the signal is taken from two orthogonally polarized antennas and fed through a hybrid ring[16,17] to two receivers as shown in Figure 5. This avoids uncertainties that might arise from switching techniques but has the disadvantage that the receivers may have different gain characteristics and it is more difficult to balance the outputs for a range of different signal levels. The signals from the 18 Mc/s null antenna, 14 Mc/s broadside array and the 26 Mc/s Yagi are each fed directly to separate receivers.

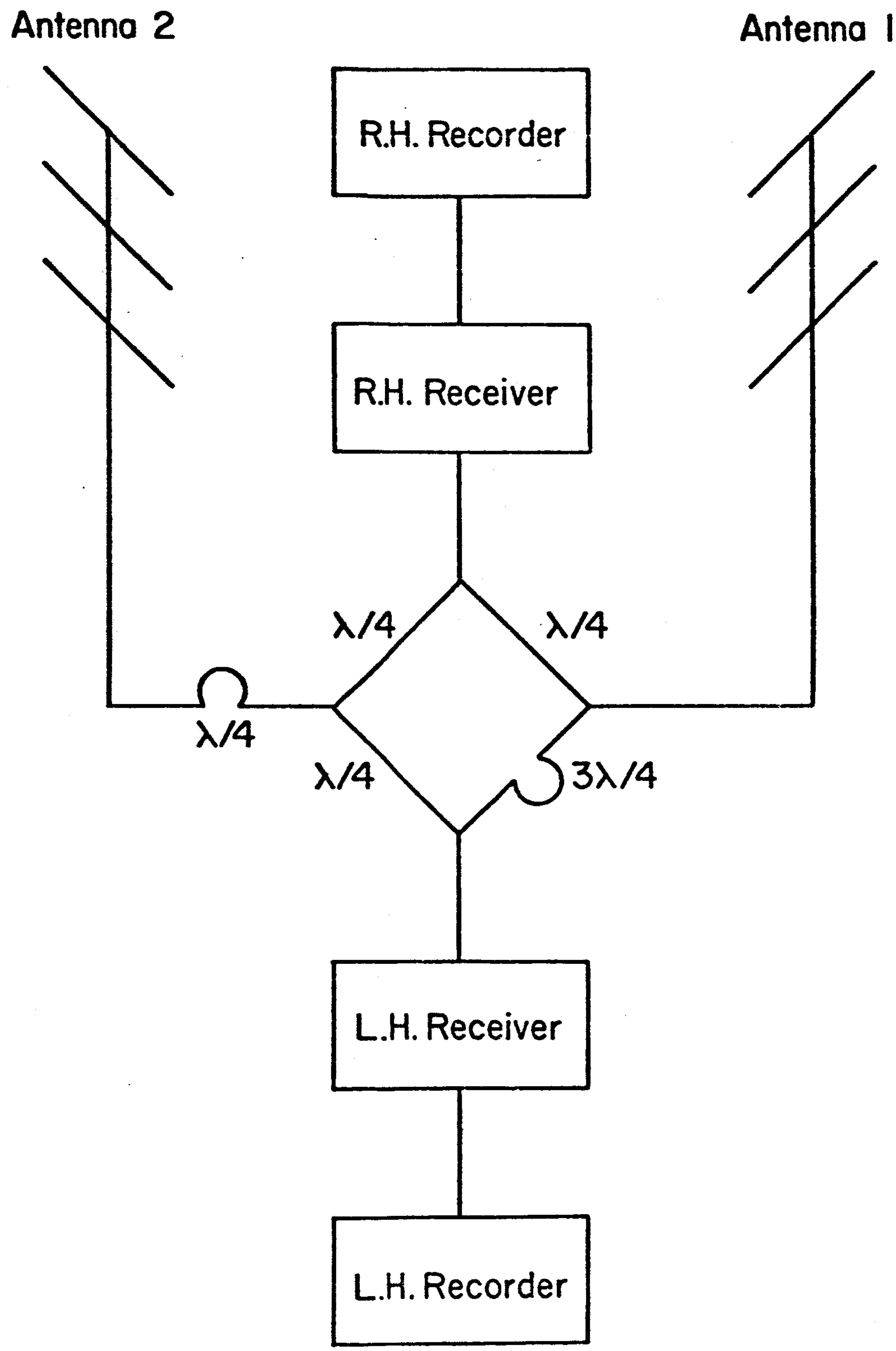


Fig. 5--Schematic diagram for the polarimeter system used at 16, 18, and 22 Mc/s.

A schematic diagram of the 18 Mc/s phase-switched interferometer circuit is shown in Figure 6. A half-wave of cable is electronically switched alternately in and out of one feed and the receiver output synchronously reversed. By this means, it is possible to suppress receiver gain fluctuations, some types of interference and the galactic background[18]. The switch frequency is 340 c/s. In order to identify station type interference, the receiver had an electronic frequency sweeping device which swept a small bandwidth of 1/2% about the center frequency with a period of two minutes.

The signals from all of the antennas except the 18 Mc/s phase-switched interferometer were recorded both on a high speed electric writing Brush recorder with varying speeds and time constants (Table 3) and an ink writing Elliott recorder with a chart speed of 6 in/hr and time constant 0.25 s. The signal from the 18 Mc/s interferometer was recorded only on an Elliott. The Brush recorder was equipped with a DC amplifier and thus could utilize the small signal from the detector stage of the receivers. This stage offers the advantage of a more stable signal for which the time characteristics have changed very little. The signal for the Elliott recorder, which required more power to operate, was taken from the audio stage of each receiver.

Since the measurement of the duration of the I-pulses was a crucial point of the experiment, considerable attention

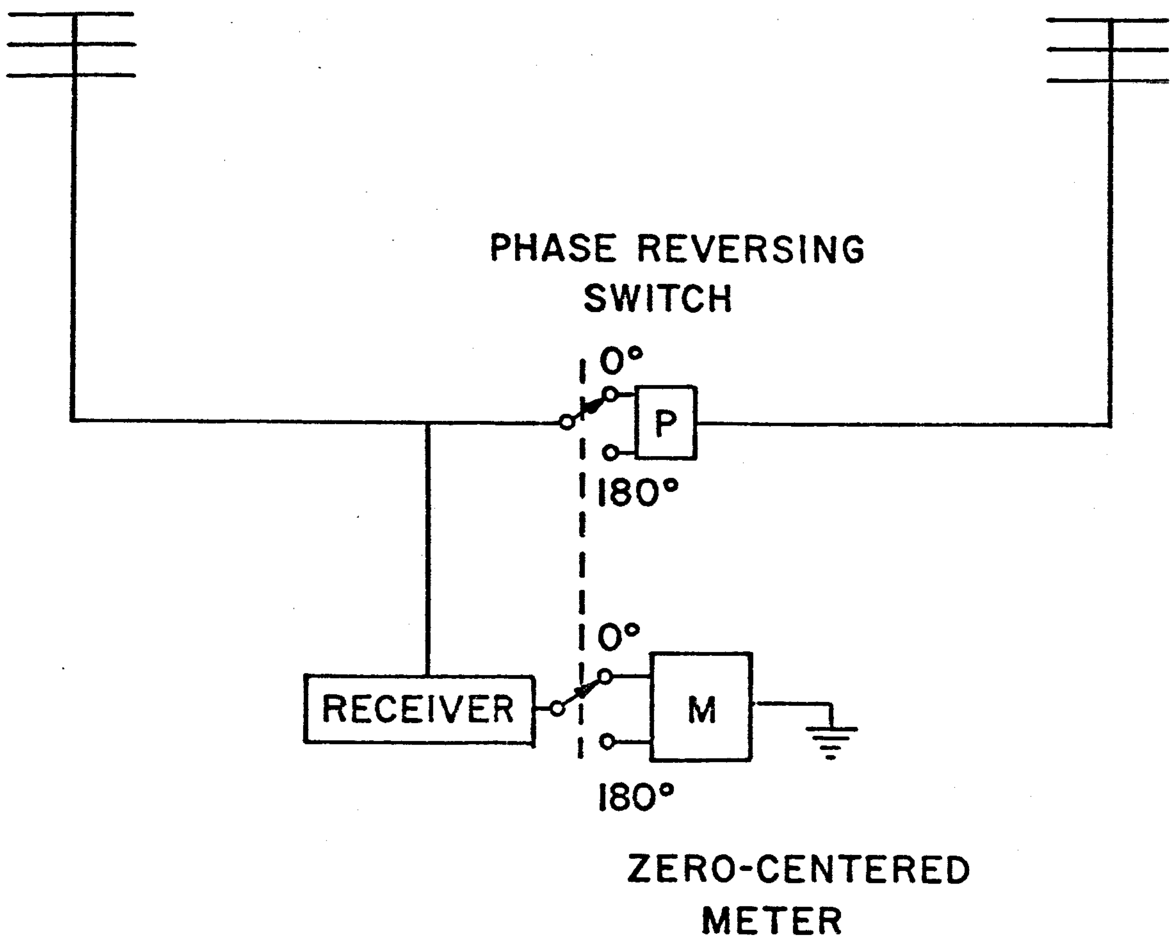


Fig. 6--Schematic diagram for the 18 Mc/s phase-switched interferometer.

was given to the problem of finding the optimum time constants and chart speeds for studying different types of activity. As shown in Table 3, three different recorder time constants were used yielding three different minimum measurable pulse widths. The pulse widths were

TABLE 3

OVERALL TIME CHARACTERISTICS OF HIGH SPEED RECORDING SYSTEM

Chart Speed	Nominal Recorder Time Constant	Minimum Measured Pulse Width at Half Height	Purpose
25 cm/hr	10	28 ms	General continuous recording
10 mm/sec	5	13 ms	Normal events
50 mm/sec	2	7 ms	I-pulse events

obtained by operating the Brush with the chart speeds shown and feeding a very short pulse through the time constant circuit to the recorder. The values given for the minimum measurable pulse width is the smallest the recorder would show under the conditions given. The fast response of the electric writing recorder allowed time resolutions that could not have been obtained with an ink writing recorder.

OBSERVATIONS

Observations were usually made for a period of four hours each side of Jupiter's local meridian transit with only the 18 Mc/s steerable Yagi antenna in use the first two and last two hours. Table 2 lists the periods during which Jupiter was observed for any signs of I-pulse activity. The daily eight hour periods of observation lasted for a greater part of a Jovian revolution, so that throughout the entire apparition all longitude regions of Jupiter were observed for approximately the same length of time. There were 18 events that contained I-pulse activity out of a total of 92 events that contained any type of activity. Table 4 gives the dates of the I-pulse events as well as the λ_{III} regions for which they occurred.

An observer was on duty at all times during the periods of observation to monitor the receivers. For normal monitoring, when no activity was being received, the Brush recorder was run at 25 cm/hr with a time constant of 10 msec. This yielded a clean trace on which any signs of activity would be readily noticed. When it was suspected that some Jovian radiation was being received, the chart speed was increased to 10 mm/s and the time constant was reduced to 5 msec. These values of chart speed and time

TABLE 4

DATES AND λ_{III} REGIONS OF EVENTS CONTAINING I-PULSES

Date	Event Duration		I-pulses	
	Begin	End	Begin	End
November 21, 1965	164	187	164	187
November 28, 1965	150	190	166	186
November 30, 1965	85	144	103	143
December 14, 1965	96	136	117	126
December 20, 1965	300	344	303	340
December 28, 1965	224	296	239	250
January 18, 1966	211	248	213	222
January 21, 1966	277	341	277	329
January 22, 1966	96	146	108	146
January 28, 1966	241	336	245	336
January 29, 1966	124	185	124	178
January 30, 1966	157	232	157	223
February 2, 1966	279	4	302	354
February 23, 1966	129	187	129	180
March 1, 1966	1	18	1	18
March 2, 1966	117	202	117	184
March 8, 1966	348	354	348	354
March 16, 1966	160	190	160	190

constant were retained until I-pulse activity was suspected. At this time the chart speed was increased to 50 mm/sec and the time constant reduced to 2 msec. This arrangement allowed a minimum time resolution for the pulses of about 7 msec. The time constants and chart speeds are listed in Table 3.

The criteria adopted for the identification of the I-pulses were:

1. Jupiter must be within the reception beam of the antenna.
2. The general recorder must show a deflection that is clearly visible above the background noise.
3. The signal must not tune out over a small bandwidth of about 0.25 Mc/s.
4. The signal might be expected to be narrow banded in comparison to static pulses which have bandwidths of several Mc/s.
5. The signal must not be identifiable as of terrestrial origin.
6. The signal might be expected to show a definite polarization in a similar manner to the long time structure of Jovian radiation.
7. The interferometer recorder must show deflections of proper phase.
8. The signal must not be received by the null antenna which has a zero of reception over an angle of about 20° each side of the vertical.

These criteria, except 4 and 6, are based upon those normally used for general observations of Jupiter and have been listed in part by Barrow[19].

Examination of Table 5 will demonstrate that Jupiter was in the beam pattern of the antennas when the I-pulse radiation was received. This table lists the time away from transit of the beginning and ends of the events. It will be noticed that all of the events except two occurred within three hours of transit. Those that occurred three hours after transit were received by the 18 Mc/s Yagi antenna which could be directed to any part of the sky. There were, however, signs of activity being received by the 16 Mc/s Yagi antenna, which was pointed at the zenith, as much as 3 1/2 hours after transit during the event of January 29, 1966. There are two possible explanations of this problem. The first is that the beam pattern is, in practice, wider than that given by the manufacturer in Figure 4; the second and more probable is that at low angles the receiving element which is perpendicular to the Earth-Jupiter line acts as a dipole with an almost circular beam pattern with the dipole as center.

To satisfy the requirement that the deflection of the recorder due to the radiation must be clearly visible above the background noise, a value of three times the RMS noise[2] is taken as a criteria for minimum intensity of the I-pulses. Intensity, however, has not been a problem in identification since in all of the events identified as containing I-pulses,

TABLE 5

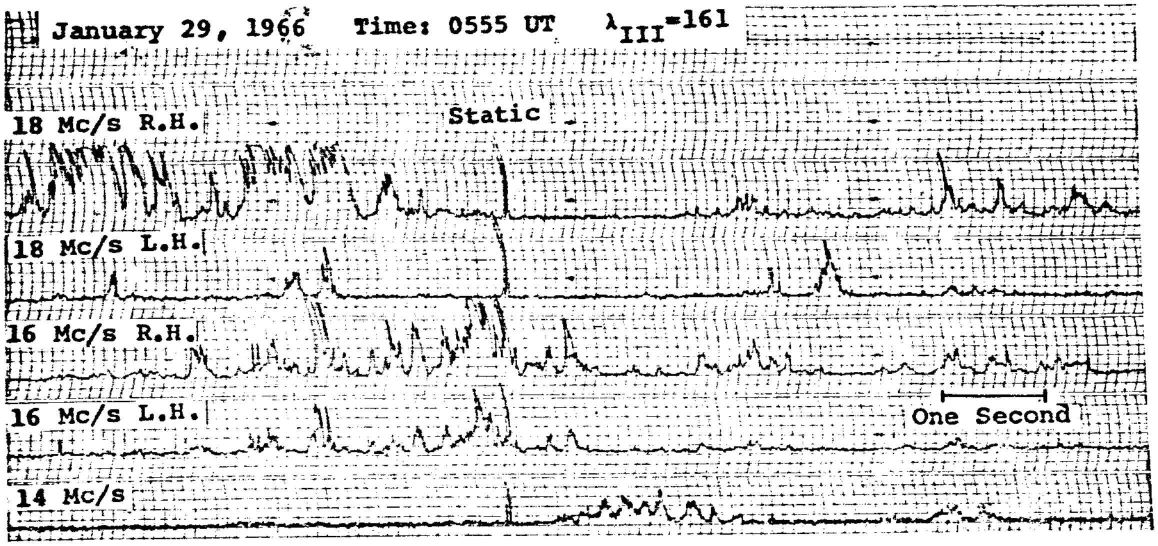
TIME AWAY FROM JUPITER'S LOCAL MERIDIAN TRANSIT
FOR BEGINNING AND END OF I-PULSE EVENTS

Date		Time away from Transit	
		Begin	End
November	21	0253	0215
	28	0134	0100
	30	0101	0026
December	14	0117	0132
	20	0150	0250
	28	0241	0221
January	18	0012	0027
	21	0020	0105
	22	0051	0125
	28	0000	0225
	29	0224	0345
	30	0041	0108
February	2	0057	0222
	23	0000	0146
March	1	0134	0202
	2	0041	0231
	8	0227	0232
	16	0413	0501

the pulses had an intensity many times greater than the minimum requirement.

Tuning the receiver over a small bandwidth was effective in discriminating between normal Jovian radiation and a distant radio station which can sometimes sound very similar, but tuning the receiver could not aid in identifying very short pulses. Auto ignition, lightning and powerline radiation are common pulses with a short duration but have characteristic sounds which are easily identified. Atmospherics, or static pulses, which sound very similar to I-pulses, can not be identified as easily. The strongest criteria for distinguishing I-pulses from atmospherics are polarization and bandwidth. The pulse marked static in Figure 7 has a bandwidth of much more than 4 Mc/s and exhibits no apparent polarization whereas all of the other pulses on the records are polarized at least partially and none appear simultaneously on more than two frequencies.

The phase-switched interferometer was not effective in identifying the I-pulses but it was conclusive for identifying the longer time structure Jovian radiaiton. The Elliott recorder on which the signal from the interferometer was recorded used a chart speed of 6 in/hr and a time constant of 0.25 sec. The time constant of the receiving and switching electronics was 0.1 sec, so that



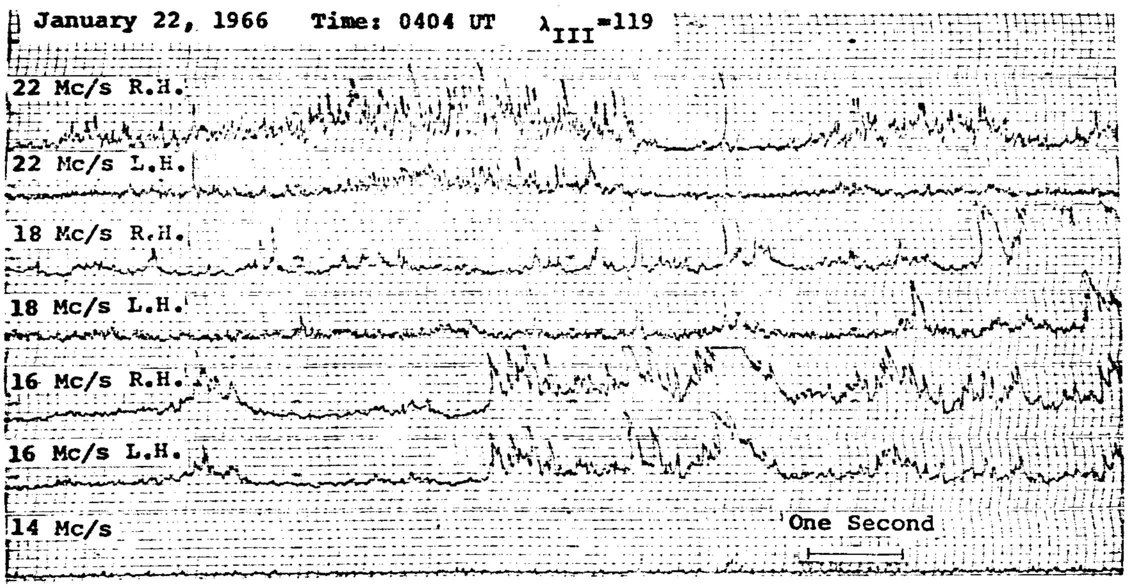


Fig. 7--High speed records containing a wide-banded static pulse and typical I-pulses.

a single I-pulse would hardly be registered by the recorder. Thus a dense group of pulses lasting as long as 5 minutes would be required to give a characteristic recorder pattern. There were nine events containing I-pulses which occurred while the interferometer was in operation. Figure 8 is a good example of an interferometer record of an event with a long duration and fairly high intensity. Figure 9 has been included as an example of an Elliott recording of a normal event.

The null antenna was effective in identifying only a small amount of radiation at 18 Mc/s. Due to a limited number of receivers available the null antenna was not in use during the entire apparition and there were only three events that contained I-pulses at 18 Mc/s while the antenna was in operation. In these events the radiation was not received by the null antenna. We will see later that correlations with the position of the Jovian moon Io and the rotation period of Jupiter are other arguments in favor of a Jovian origin for the I-pulses.

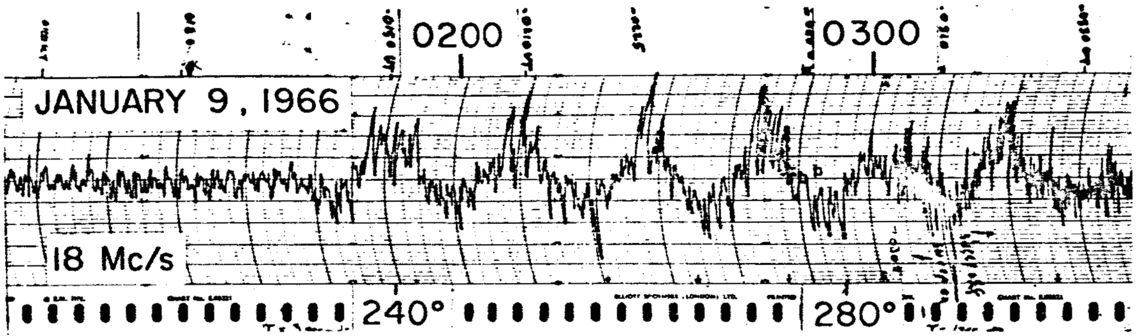


Fig. 8--Typical record of interferometer fringes

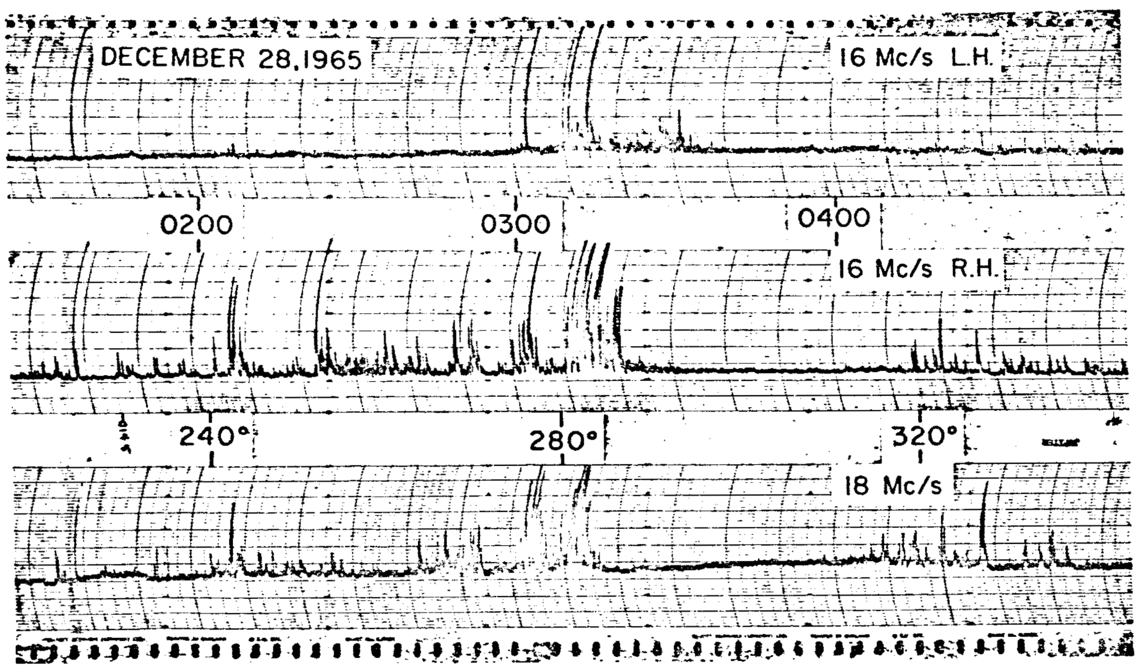


Fig. 9--Typical record of a normal event

DISCUSSION

Listed in Table 3 are the dates of all the I-pulse events with the corresponding values of λ_{III} for the I-pulse events and the normal events during which the I-pulses occurred. It will be noticed from this table that the I-pulses tend to begin after the start of a normal event and to cease before the normal event ends. On one occasion, November 21, 1965, an event occurred which contained I-pulses only.

In general, there appears to be three ways in which I-pulses occur. They may occur as isolated events, or singly, as shown in Figure 10, with separations from a few tenths of a second to several seconds. Secondly, they may occur in groups, the envelope of which has the appearance of a normal burst, sometimes being grouped so closely that the recorder stylus can not return to its zero position between pulses. This type of occurrence is shown on the 22 Mc/s channels in Figure 11. Thirdly, the I-pulses may appear superimposed on top of a normal pulse as on the 16 and 18 Mc/s channels in Figure 12. The I-pulses tended to occur singly at the beginning of an event and to group together as the event progressed, becoming less dense again toward the end of the event. I-pulses may at times appear

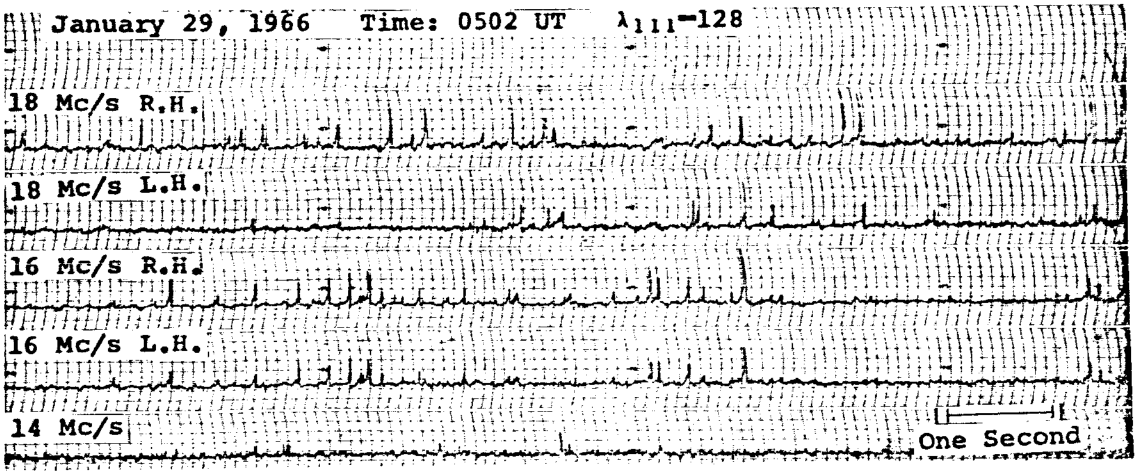


Fig. 10--High speed record of isolated I-pulses.

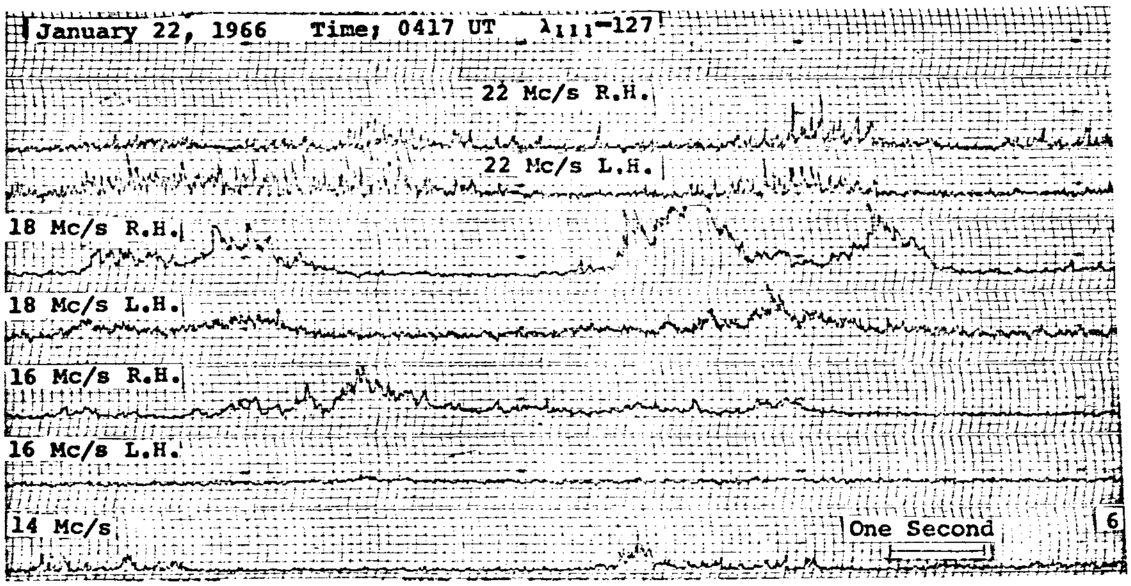


Fig. 11--High speed record of grouped I-pulses.

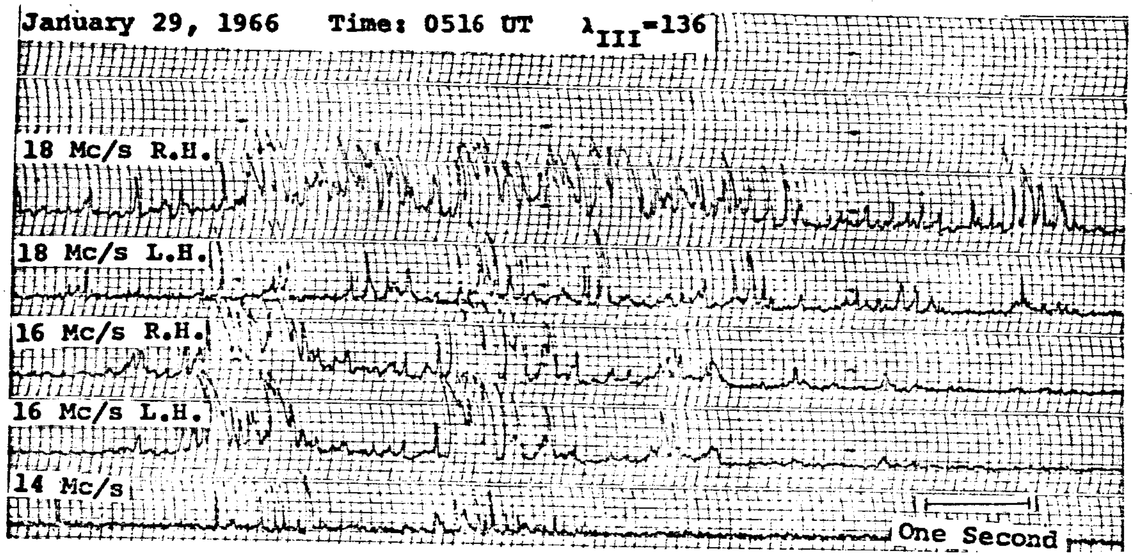


Fig. 12--High speed record of I-pulses superimposed on normal pulses.

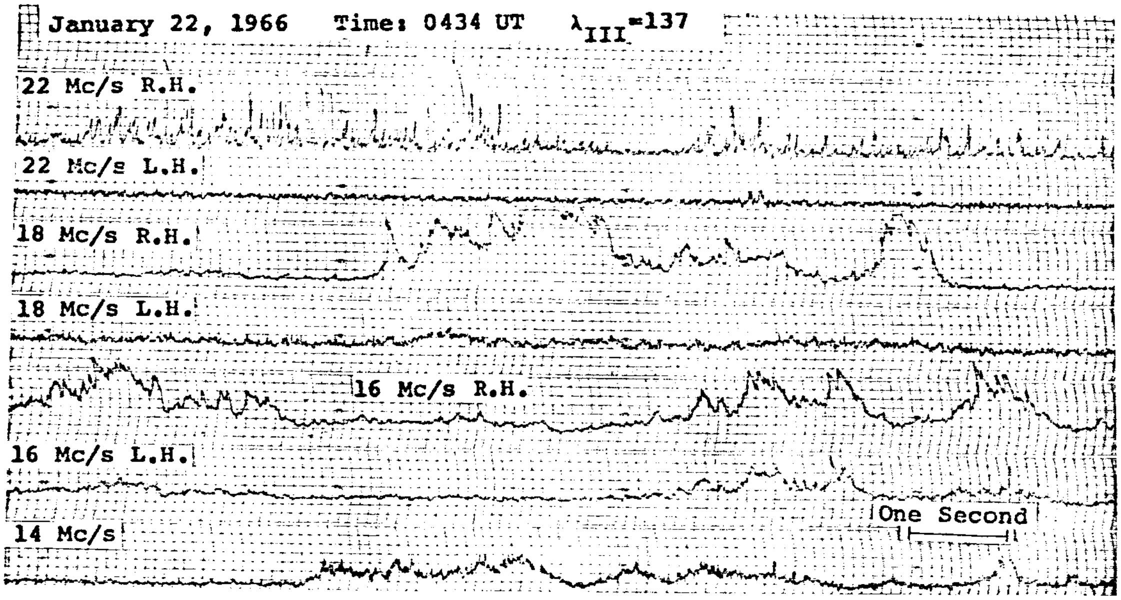


Fig. 13--High speed record with I-pulses on 22 Mc/s and normal pulses on 14,16 and 18 Mc/s.

on one frequency while normal pulses occur on the other frequencies as shown in Figure 13.

The durations of about 700 I-pulses have been measured and a histogram of the number of pulses for each 10 msec interval has been prepared. Figure 14 shows that almost all of the pulses have durations less than 50 msec. Since the amount of data is so large, one typical event and a single frequency was chosen for this histogram. However, data from another event have been examined and the results are similar.

A histogram has been prepared for the number of events against each 5° interval of λ_{III}. The histogram, shown in Figure 15, has been prepared for I-pulse events and for all events. The histogram for all events is very similar to histograms that have been made for all previous apparitions of Jupiter with the three characteristic source regions and the region of no emission which have been designated D, B, A and C[2] from left to right on the histogram. The histogram for I-pulses is similar to the histogram for all events except that the I-pulse events seem to be more closely related to the subsidary sources B and C than to the main source A. It is also significant that the null region, D, is present in the histogram for I-pulses. This correlation adds considerable weight to

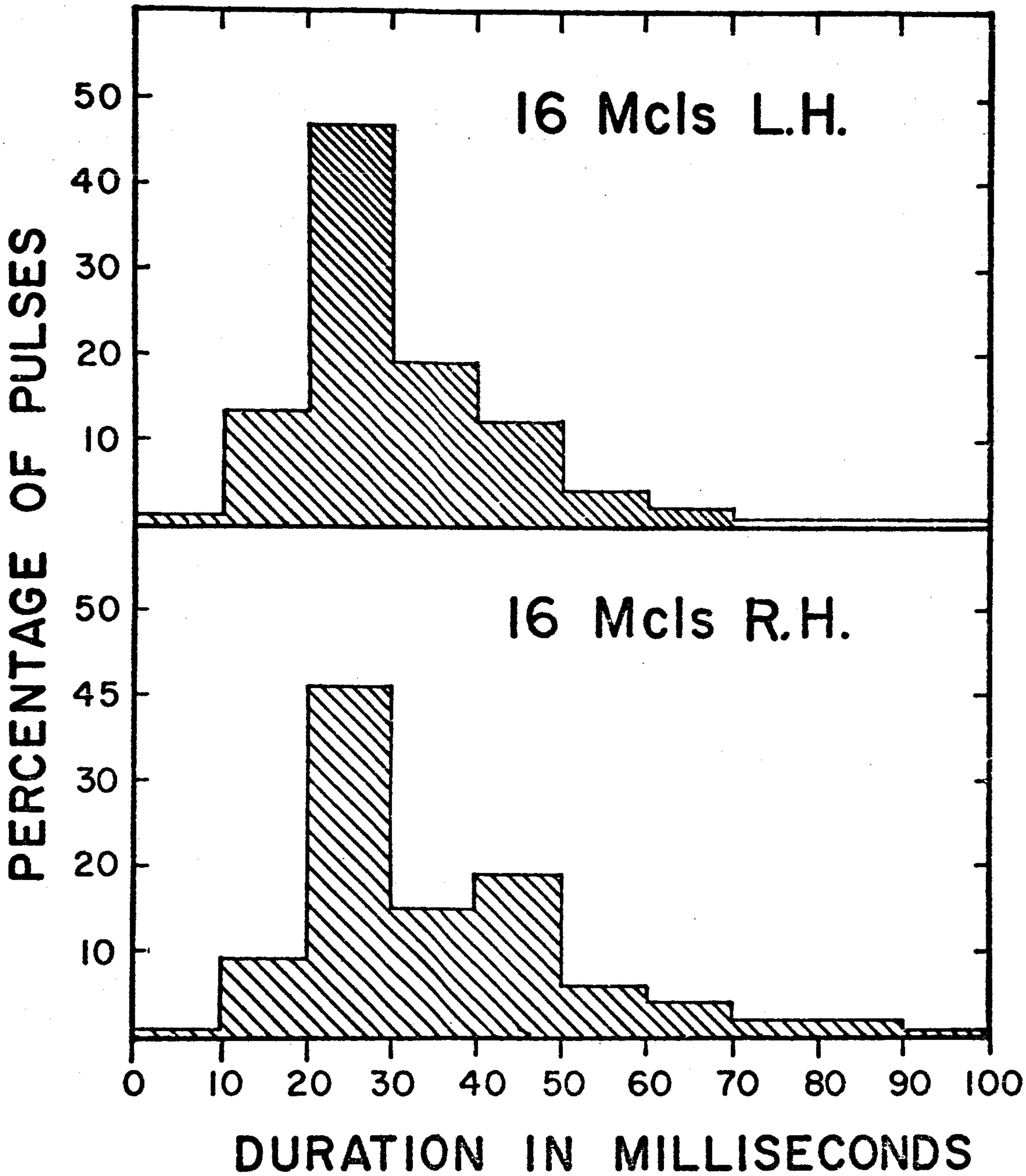


Fig. 14--Distribution of I-pulse durations.

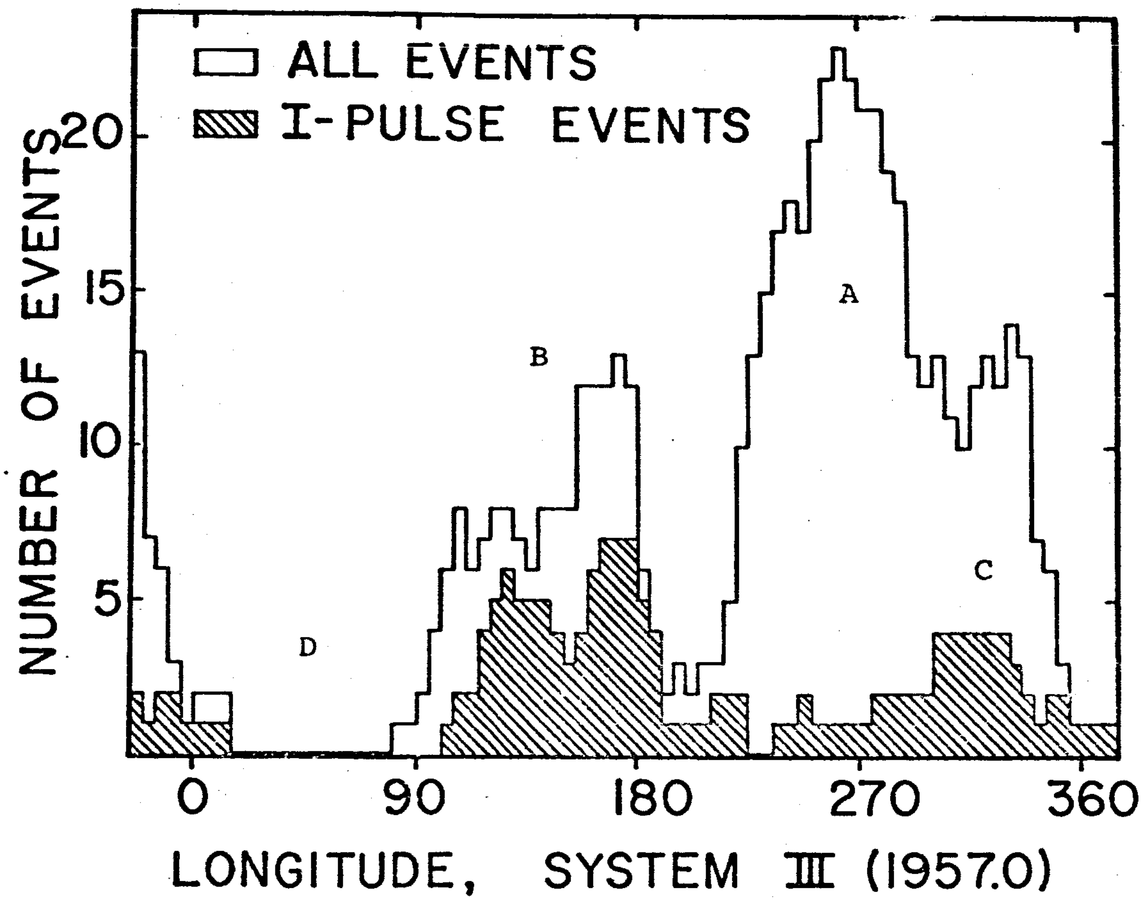


Fig. 15--Histograms of I-pulse events and all events for system III longitude.

the identification of the I-pulses as of Jovian origin. It is extremely unlikely that radiation of terrestrial origin would be correlated with the rotation period of Jupiter.

Histograms of the number of events against the departure of Io from superior geocentric conjunction have been prepared similar to those introduced by Bigg[8]. The I-pulse histogram is based on only 18 periods of activity. The statistics are not as good as those for the λ_{III} histograms since the revolution period of Io is approximately four times the rotation period of Jupiter, and thus only one fourth as many revolutions of Io were observed as rotations of Jupiter. However, there does appear to be some tendency for the I-pulses to exhibit the same kind of correlation as that found by Bigg. The histogram which was made using the normal event data obtained in the 1965 apparition also appears to show some correlation. These histograms are shown in Figure 16. The correlation of the radiation with the position of the moon Io is also an indication that the radiation is of Jovian origin.

In 1963, Ellis and McCulloch[20] predicted, from theoretical considerations, that the axial ratios of the polarized Jovian radiation would have a distribution whose peak would be given by the relation

$$A = \mp \cos \alpha_m \qquad (1)$$

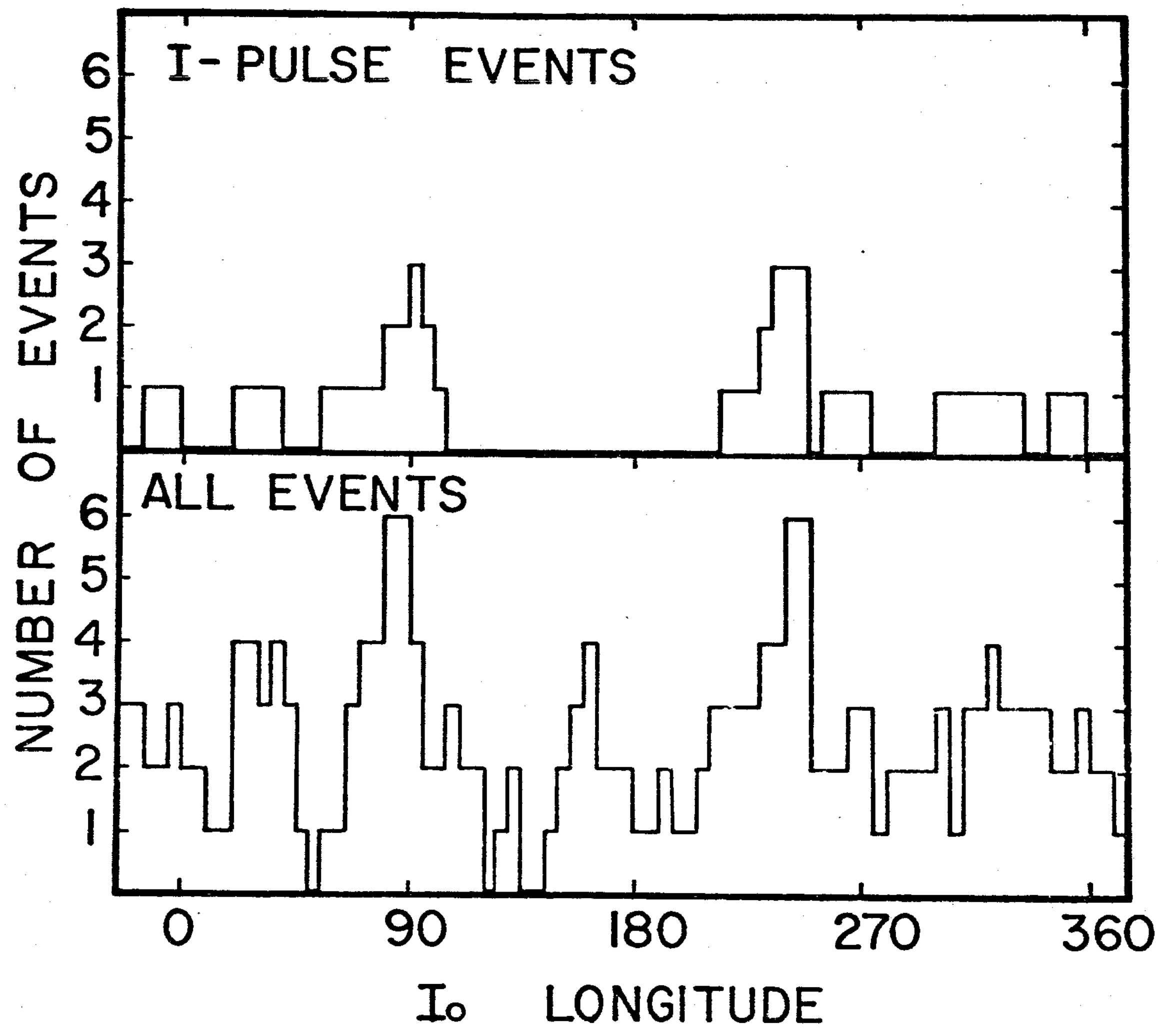


Fig. 16--Histograms of I-pulse events and all events for the departure of Io from superior geocentric conjunction.

where α_m is the angle of a postulated Jovian magnetospheric emission cone and the minus/plus signs indicate right- or left-handed polarization respectively.

Assuming that the radiation is 100% elliptically polarized* and that the square root of the combined intensity of the galactic background and Jovian radiation is proportional to the recorder deflection, the equation

$$A = \frac{(D_1^2 - G_1^2)^{1/2} - (D_2^2 - G_2^2)^{1/2}}{(D_1^2 - G_1^2)^{1/2} + (D_2^2 - G_2^2)^{1/2}} \qquad 2$$

may be used to calculate the axial ratio. Here D_1 and D_2 are the deflections of the left-and right-hand polarization channels respectively, and G_1 and G_2 are the galactic levels recorded on each channel respectively. The numbers of pulses are summed in axial ratio intervals of $|0.1|$ to obtain the distribution shown in Figure 17. In Figure 18 are distributions by Dowden[21] and by Barrow[22] utilizing normal pulse data. The agreement between these distributions and the I-pulse axial ratio distribution is quite good. The

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*A Thesis being completed by D. P. Morrow at Florida State University presents measurements indicating that the degree of polarization is about 80%.

I-pulse axial ratio distributions also have the same general shape of the distribution predicted by Ellis and McCulloch.

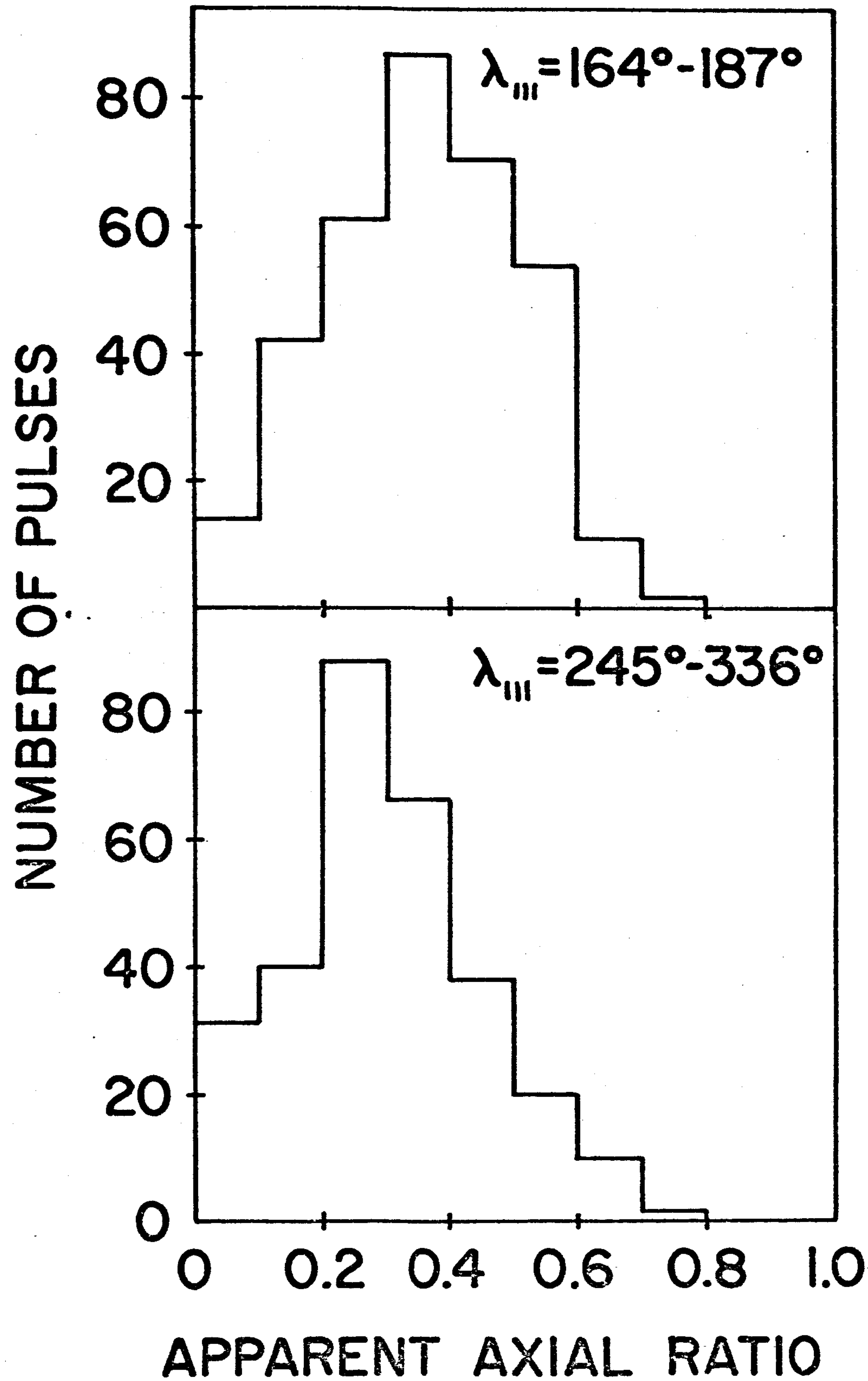

Fig. 17--Distribution of I-pulse axial ratios.

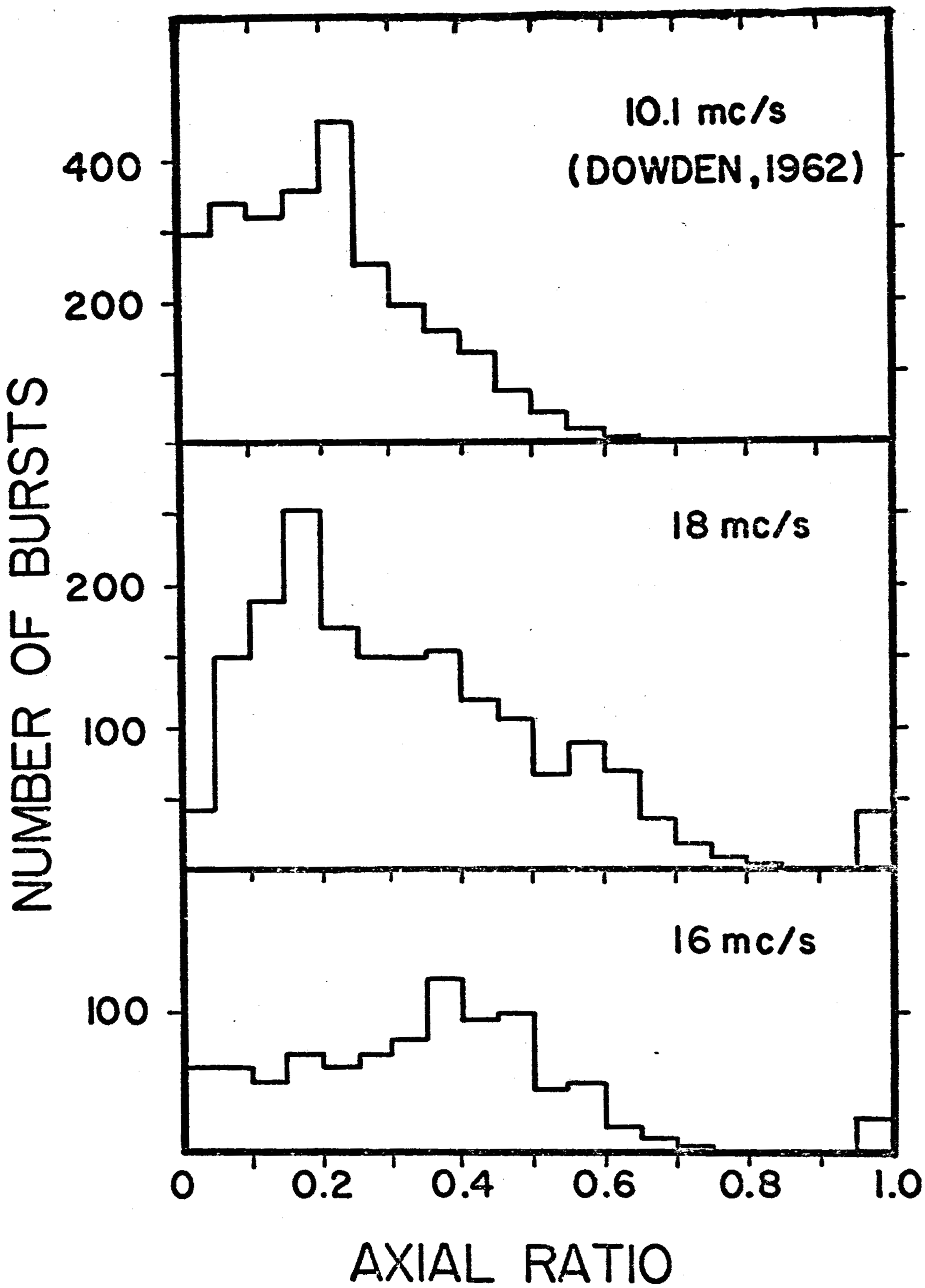

Fig. 18--Distribution of normal pulse axial ratios by Dowden(21), 10.1 Mc/s, and Barrow(22), 17 and 18 Mc/s.

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The results of the experiment show conclusively that the I-pulse radiation has its origin at Jupiter. The results may be summarized as follows:

1. Jupiter was in the beam pattern of the antennas when the radiation was received.

2. The I-pulses were not received by the null antenna.

3. The polarization of the I-pulses was similar to that of the normal radiation with the axial ratios having a similar distribution for the examples considered.

4. The I-pulses were narrow banded in comparison with static pulses of terrestrial origin. A single I-pulse was never observed with a bandwidth as great as 4 Mc/s whereas static pulses have a bandwidth much greater than 4 Mc/s.

5. The I-pulse radiation was correlated with the rotation period of Jupiter. Particularly significant was the absence of radiation in the λ_{III} region from 20° to 100°.

6. The I-pulse radiation appeared to be correlated with the period of revolution of the Jovian moon Io.

Although the I-pulse radiation is of Jovian origin, the results do not show where the radiation gains its I-pulse structure. Does the radiation originate as long bursts that are altered in the interplanetary medium? Does the I-pulse structure originate at Jupiter? If so, does it have the same origin as the time structure of the normal radiation or does it have an origin of a different nature?

It is believed that much of the fine structure of the normal radiation comes from scintillations in the earth's ionosphere and/or the interplanetary medium. Evidence for ionospheric scintillation is considerable[23], as several spaced site experiments have shown. At times there is very little correlation between sites, with whole groups of bursts being observed at one site and not at another. At other times there is partial correlation with bursts that appear at one site being greatly distorted at the other and on other occasions there is perfect correlation even for bursts with durations on the order of 10^{-2} sec. It has also been suggested that diffraction could be a cause for the fine structure[24].

Examination of the λ_{III} histogram, Figure 15, shows that the I-pulse radiation appears to be associated with the subsidary sources B and C rather than with the main source A. Radiation from a narrower source should produce greater scintillation in much the same way as stars twinkle whereas planets do not. There is some qualitative evidence in addition to the λ_{III} profile that the radiation may be from narrower source regions. The I-pulses are usually much more intense than normal pulses when both are present, which may indicate that the I-pulses originate in a region with a stronger magnetic field. A stronger magnetic field would be expected at higher latitudes on Jupiter. A source at higher latitudes would be narrower and would produce more intense radiation. A graph of relative power against λ_{III} for 15.7 Mc/s normal radiation by Ellis and McCulloch[20] shows that slightly more intense radiation comes from sources B and C.

A study of the axial ratio distributions may lead to the answer to the last question. As mentioned in the introduction, a burst is defined as a pulse or group of pulses separated from other pulses by one second or more. If the I-pulse structure is modified normal radiation, the axial ratio of each group or burst of pulses should be represented by the most intense pulse of the group. If the individual axial ratios differ greatly from the axial ratio of the group, then it might be inferred that the pulses originate individually, or if the axial ratios do not vary then this could be taken as evidence that I-pulses are modified normal radiation.

Further work with I-pulses might include:

1. Axial ratio distributions for several events from each of the longitude regions A, B and C to determine if the variation in the peaks of the distributions are consistent with the prediction of Ellis and McCulloch and the width of the regions given by the λ_{III} histograms.

2. Measurements to compare the power of the I-pulses with that of the normal radiation. This could give some insight to the Jovian latitudes of the sources assuming the different types of radiation have the same origin.

3. A spaced site experiment to determine whether or not the I-pulse structure is associated with the earth's ionosphere. If I-pulses are observed simultaneously over a wide baseline, they could be conclusively disassociated with the earth's ionosphere.

4. Accumulation of more data for the λ_{III} histograms to determine if the I-pulses are actually more closely related to sources B and C or if the relation was caused by a lack of sufficient data in the past apparition.

5. Statistical analysis of all the I-pulse events rather than selected events.

Clearly, much work remains before the relation between I-pulse radiation and normal radiation can be definitely established.

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